Fermilab
Main Injector Department

# MI-NOTE 0128

## Cyclic, High-Power Tests of Main Injector Dipoles at E4-R

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On October 25, 1994, we commenced a "thermal test" of four, 6-m Main Injector dipoles at E4-R. The test was intended to thermally cycle the magnets, with the goal of at least 500 thermal cycles. The test was concluded in early December, with approximately 1350 cycles, as discussed below. The tests were motivated by the earlier measurements at MTF on a single dipole, and by the follow-up calculations done by A. Lipski et. al, reported elsewhere [1,2]. The test is intended to see if there are any adverse effects on the coil insulation from drastic changes in the AVERAGE power level of the magnets. Such changes occur primarily when the machine is shutdown for accesses; it has nothing to do with the AC power changes over periods of a few seconds, which are averaged out by the thermal capacity of the copper coils.

The dipoles subjected to the thermal cycles were the following:
IDM001 - an R&D dipole with B-stage insulated, Fermilab fabricated coils.
IDA002 - a pre-production dipole with Everson coils, vacuum-impregnated by Tesla
IDB001 - a pre-production dipole with Everson coils, vacuum-impregnated by Everson
IDA001 - a pre-production dipole with Everson coils, vacuum-impregnated by Tesla

Prior to the test, the dipoles were inspected, some areas photographed, and the system was corona-tested. The corona test showed the onset of corona at an rms voltage of 1.6 kV. The current in the magnets was monitored by the Fermilab controls system data-logger facility, as were the four magnet coil temperatures (by thermocouples mounted on the outside turn of the coil) and two Low Conductivity Water (LCW) supply and two LCW return temperatures. The thermocouples directly on the coils gave lower readings than the LCW return, which is attributed to the combination of the coil insulation and air-cooling of the thermocouples. The LCW was supplied from the Main Ring system, via the Main Ring tunnel, and provides flows of 9.0-9.5 GPM per dipole [3]. The round-trip path length for the LCW from the E4 Service Building to E4-R is 300-400 feet, resulting in a transit-time delay of about two minutes. The magnets and the power supply were also protected from over-temperature by Klixons connected to the electrical safety system.

Two different thermal cycles were used during the test. The initial cycle consisted of exciting the magnets to 9500 ADC for 30 minutes, then turning the power off for 30 minutes. This excitation generates approximately 75 kW per dipole, approximately four times the peak average power expected for the FMI. The excitation of the magnets caused the LCW controller in E4 to oscillate by as much as 12° C with a period of about 1 minute, as shown in the lower trace in Figure 1. After about 60 cycles to 9500 A (equals 60 hours of operation), the power supply tripped on an overtemperature indication. The trip occurred on a Friday evening, and the power supply was not reset until Monday. Another trip occurred after another 30 cycles the following Tuesday, on magnet overtemperature.

Since the plans were to shut down the E4-R facility the following week for changing transformers, it was decided to change the thermal cycle. On November 2, the cycle was changed to 8500 ADC for 20 minutes, then off for 10 minutes. This cycle is shown in Figure 2. It was intended both to avoid the overtemperature trips, and to double the number of cycles per hour. Due to delays in the arrival of equipment required for the transformer change, the tests continued until December 5. During this second period, approximately five weeks, there were no trips of the system. However, there were a number of Main Ring enclosure accesses, which required racking out the 13.8 kV transformers which feed both the Main Ring and the E4-R facility. Some time was also taken for power supply studies at E4-R. During one shutdown, on November 11, the system was corona-tested again, with the onset of corona at 2.2 kV. The improvement was attributed to the colder outside temperatures and lower humidity. During this period, about 1260 cycles to 8500 A were done, as shown in the following table.

| Week of | # Cycles | |
|---|---|---|
| 10/30 | 230 | (Started 8500 A Test on 11/2) |
| 11/7 | 218 | (Main Ring Accesses) |
| 11/14 | 260 | (Some PS Studies) |
| 11/21 | 328 | |
| 11/28 | 205 | (+ ~20 Cycles, Week of 12/5) |
| Total (Both Modes) | ~1350 Cycles | |

The ramp cycle history, as retrieved from the datalogger, is shown in Figure 3(a) through 3(f). Some annotations are made to indicate various events. At the completion of the test, the magnets were again inspected, and (some time later, due to the equipment not being available) corona-tested. The corona test (on February 2) again showed onset of corona at 1.6 kV. There were no obvious changes in the appearance of the coils.

## Summary

The test was, by its nature, one that does not produce quantifiable results and involved a small statisical sample. Even if the magnets had shown signs of degradation, we would have had to ponder the question of whether the magnets were simply overstressed too much. Also, the thermal cycling effects on the insulation were likely exacerbated by the oscillations in the LCW control system. In addition, the coils were pre-production coils, almost certainly of lower quality than the production coils. The fact that these magnets survived this severe temperature cycling, far worse than anything the magnets will experience during operation, gives one great confidence in the integrity of the insulation and its ability to withstand the thermal cycles associated with operation.

## Acknowledgment

I would like to acknowledge the efforts of Arie Lipski in providing the motivation for conducting this test, for his numerous suggestions for the test procedure, and for his assistance in coil inspections. I would also like to acknowlege the efforts of the power supply group in conducting this test. The setup for the test was substantial, as was their effort in monitoring it and getting it running again following trips or accelerator accesses. Thanks to all involved.

## References

1. MI Note 0131, "Summary Report on the MIR 20.0 ft Dipole Magnet Performance/Thermal Test", Arie Lipski, June 24, 1994

2. MI Note 0132, "FE Thermal Stress Analysis of the Main Injector Dipole Coil", Eric Haggard, September 22, 1994.

3. The LCW system pressures and flows have been measured for a typical "hydraulic cell" by Karl Williams.

Console Location 117,
Fast Time Plot

26-OCT-1994 11:38

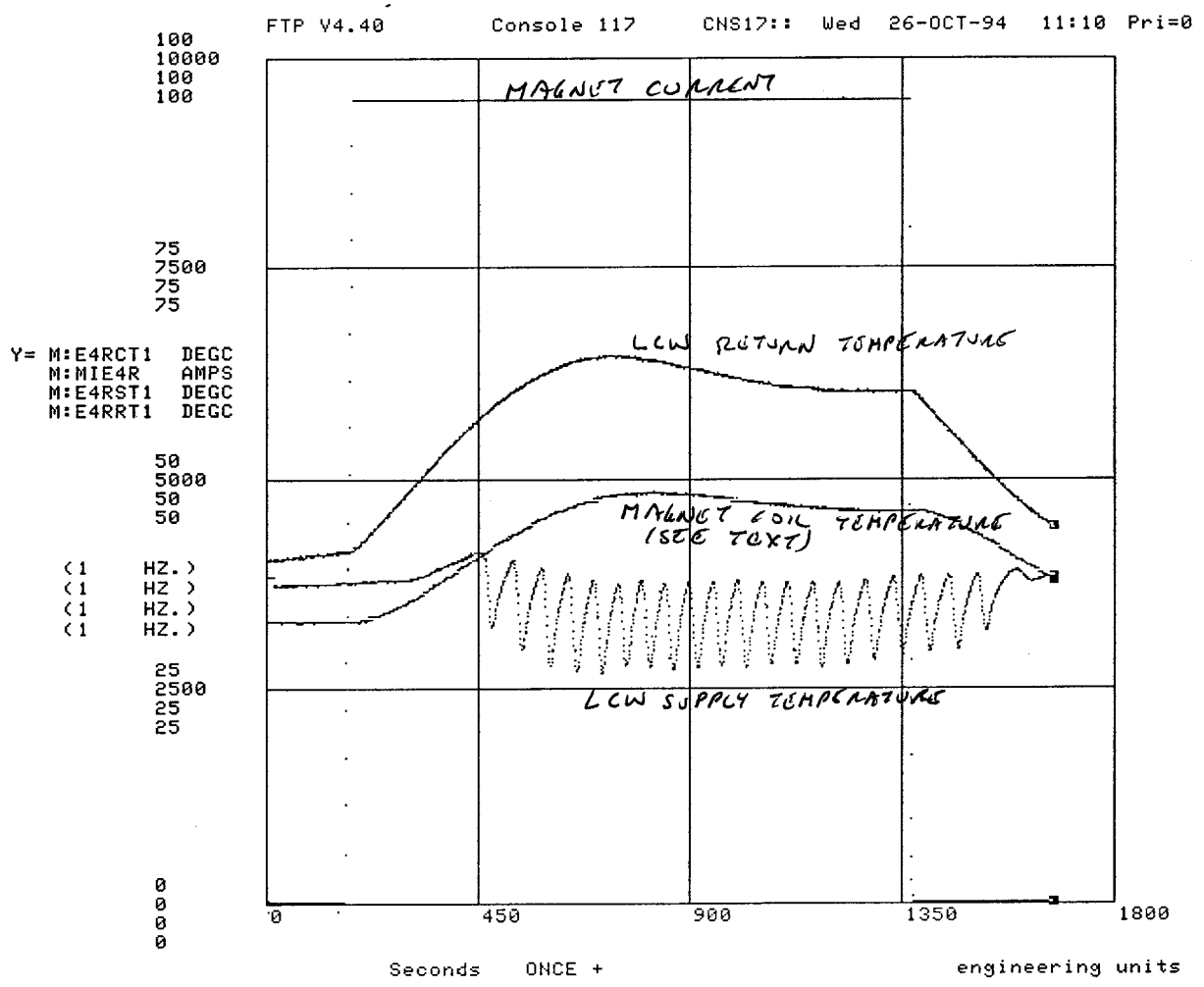



Figure 1

Console Location 9,
Fast Time Plot

3-NOV-1994 09:02

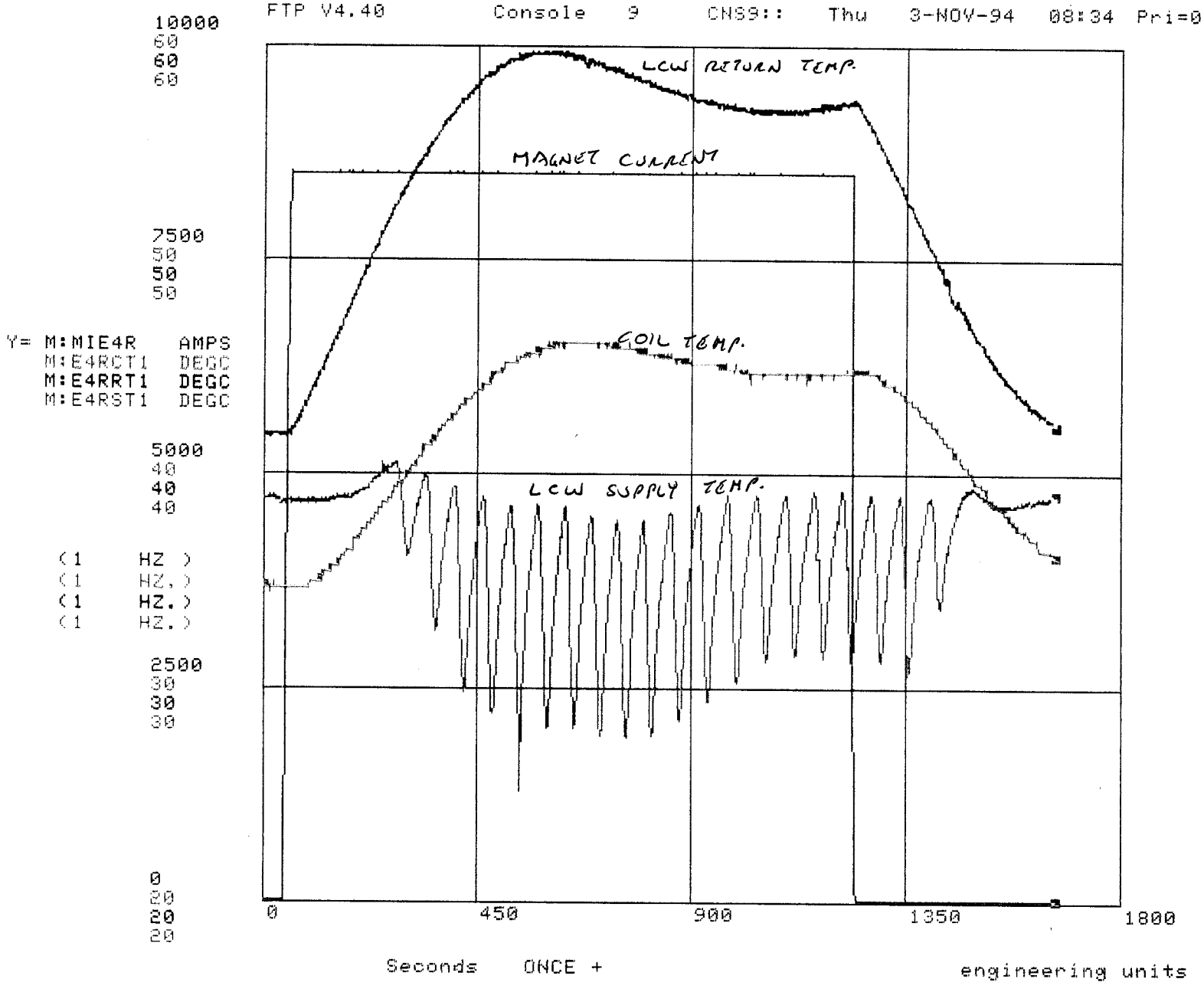
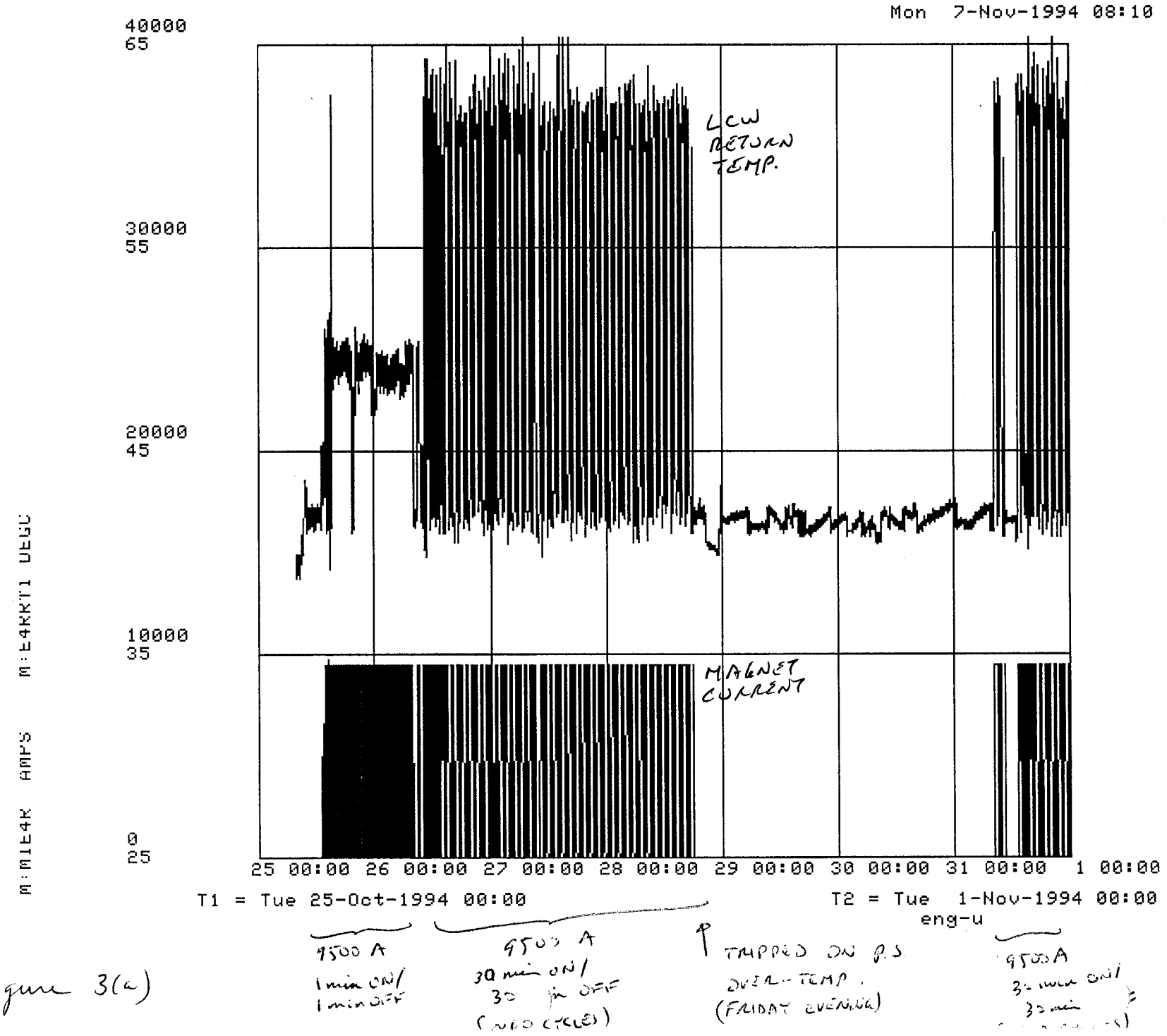



Figure 7



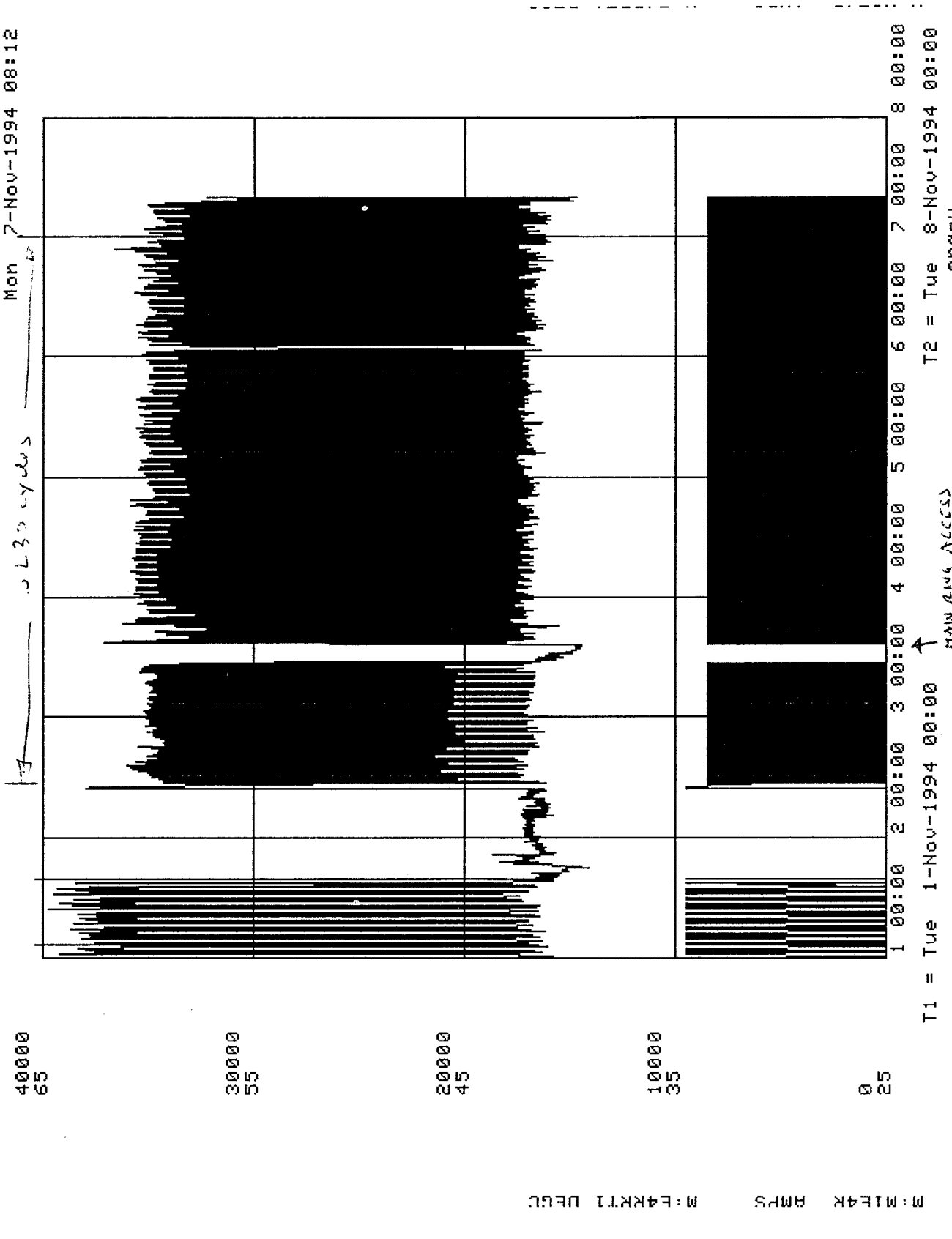

Console Location 9,
"MI E4R MAG TEMP

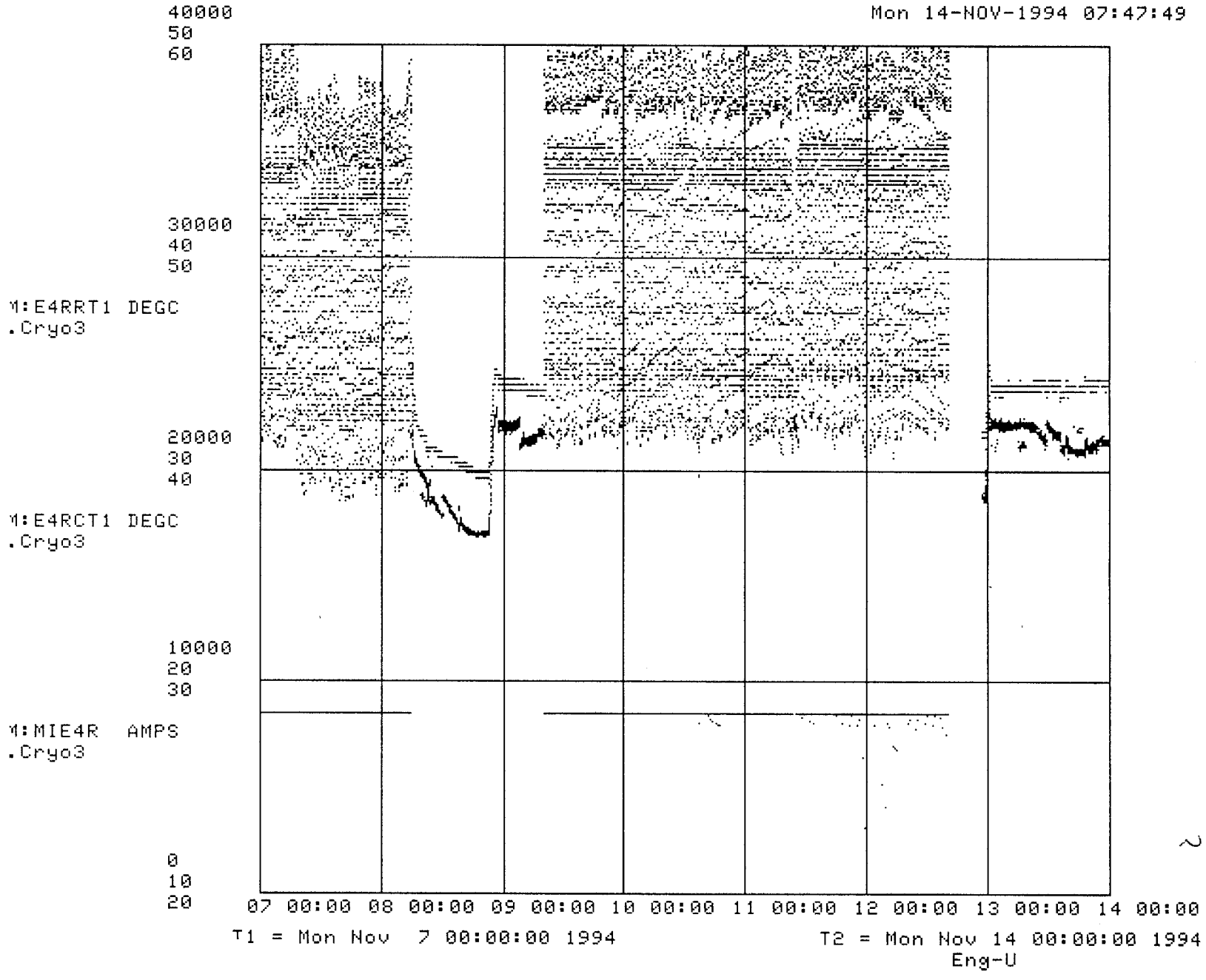
7-NOV-1994 08:11

Figure 3(a)

Console Location 9,
"MI E4R MAG TEMP

7-NOV-1994 08:12






Console Location 9,
"MI E4R MAG TEMP

14-NOV-1994 07:49

~ 210 cycles

Figure 3(c)

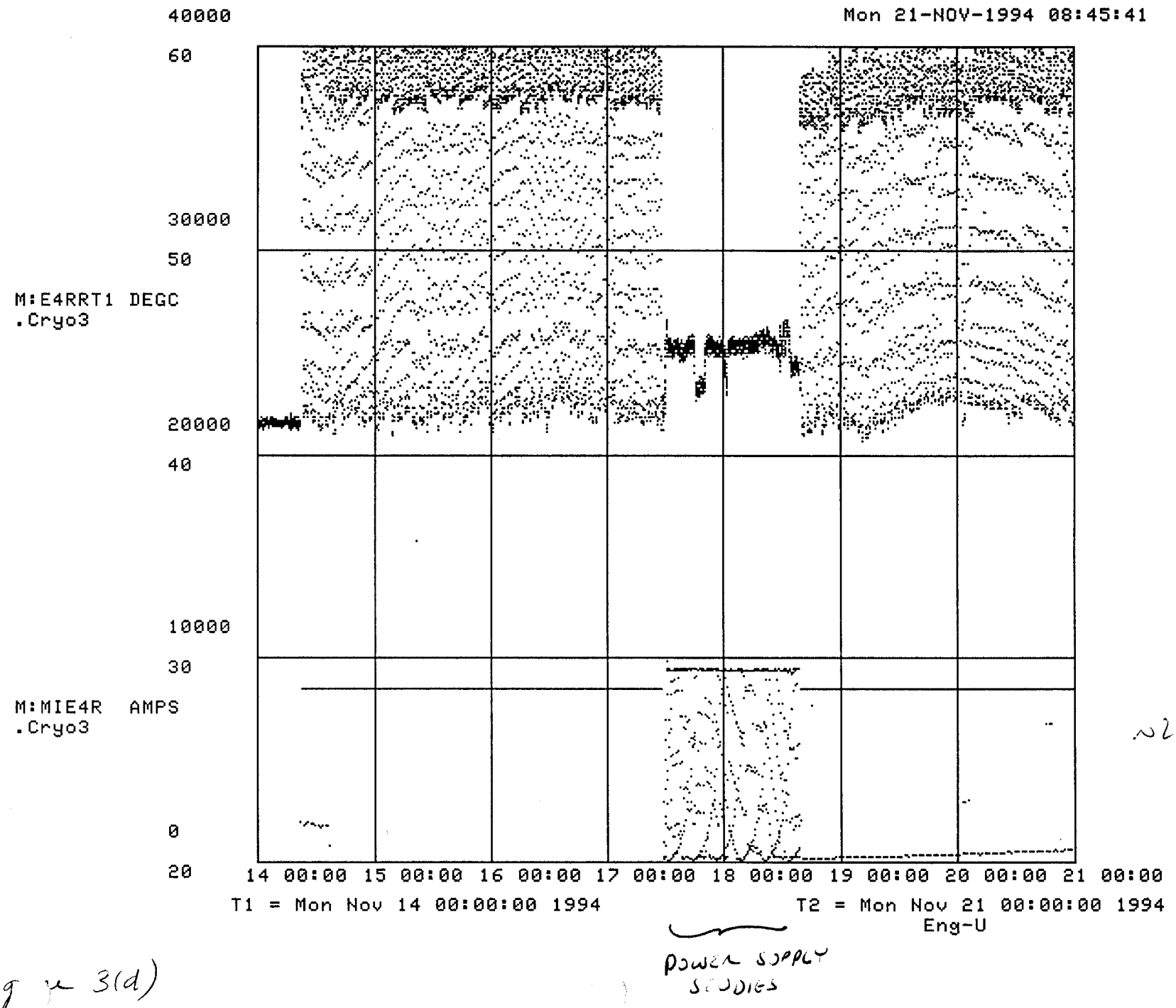

Console Location 9,
"MI E4R MAG TEMP
21-NOV-1994 08:46
Mon 21-NOV-1994 08:45:41
40000
60
30000
50
M:E4RRT1 DEGC
.Cryo3
20000
40
10000
30
M:MIE4R AMPS
.Cryo3
0
20
14 00:00 15 00:00 16 00:00 17 00:00 18 00:00 19 00:00 20 00:00 21 00:00
T1 = Mon Nov 14 00:00:00 1994
T2 = Mon Nov 21 00:00:00 1994
Eng-U
~260 cycles
Power supply studies

Figure 3(d)

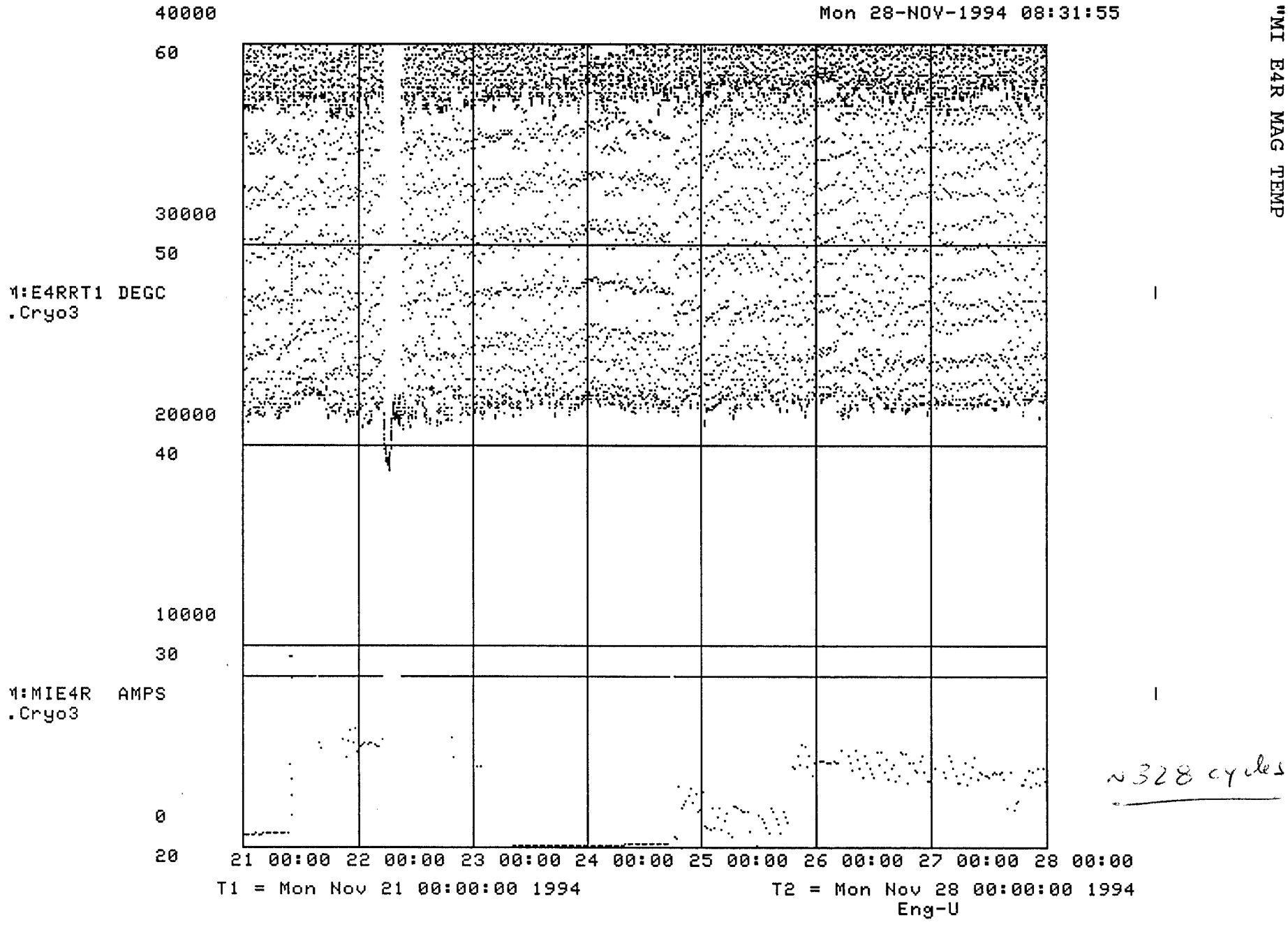
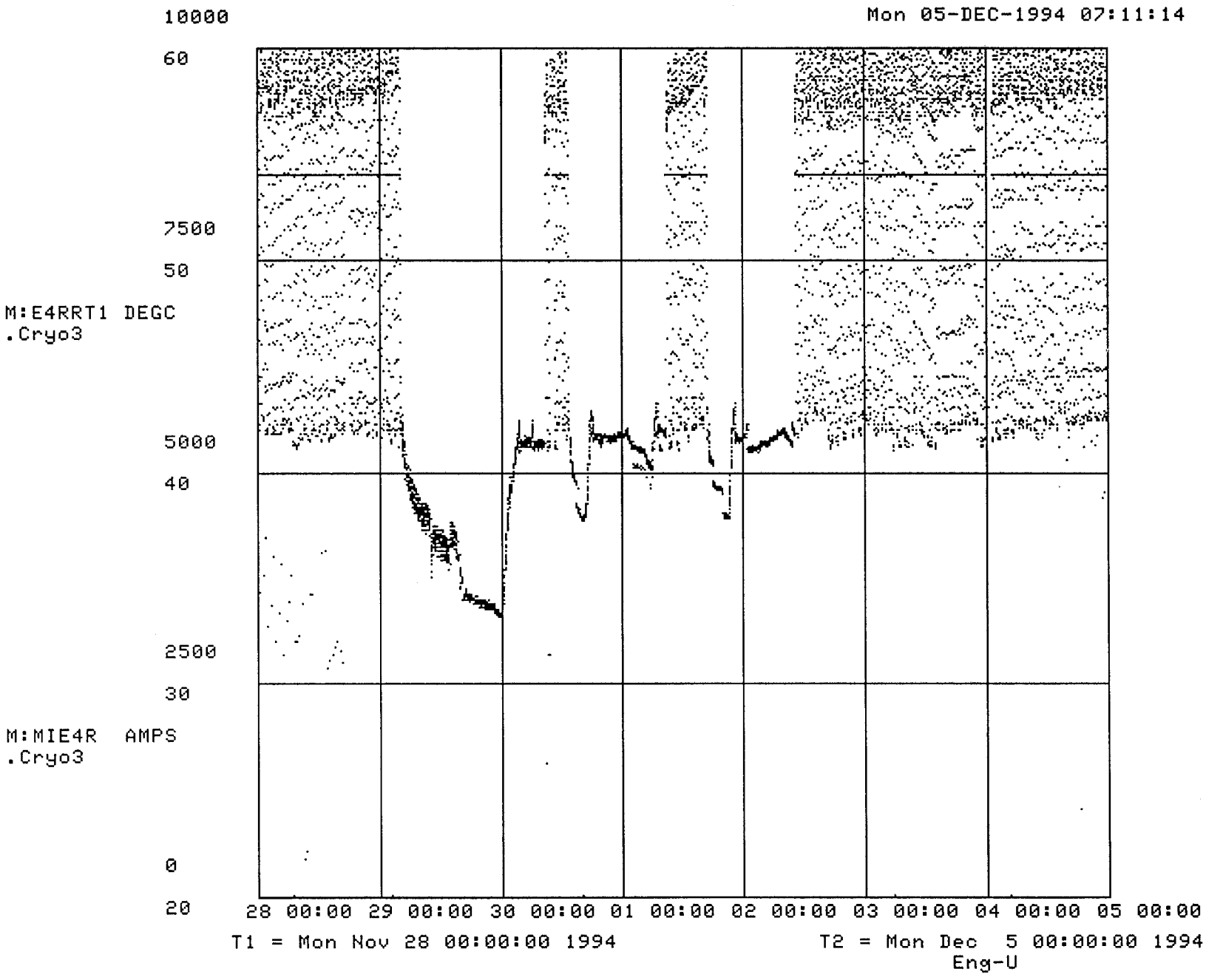

Console Location 9,
"MI E4R MAG TEMP
28-NOV-1994 08:32
Mon 28-NOV-1994 08:31:55
40000
60
30000
50
M:E4RRT1 DEGC
.Cryo3
20000
40
10000
30
M:MIE4R AMPS
.Cryo3
0
20
21 00:00 22 00:00 23 00:00 24 00:00 25 00:00 26 00:00 27 00:00 28 00:00
T1 = Mon Nov 21 00:00:00 1994
T2 = Mon Nov 28 00:00:00 1994
Eng-U
~328 cycles

Figure 3(e)




Console Location 9,
"MI E4R MAG TEMP

5-DEC-1994 07:12

Figure 3(f)